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TECHNICAL REPORT NO. 67-15  
MULTICOMPONENT STRAIN SEISMOGRAPH  
Quarterly Report No. 7, Project VT/5081  
1 January to 31 March 1967

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GEOTECH

A TELEDYNE COMPANY

TECHNICAL REPORT NO. 67-15

MULTICOMPONENT STRAIN SEISMOGRAPH  
Quarterly Report No. 7, Project VT/5081  
1 January to 31 March 1967

Sponsored by

Advanced Research Projects Agency  
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ARPA Order No. 624

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11 April 1967

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Multicomponent Strain Seismograph

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## CONTENTS

	<u>Page</u>
ABSTRACT	
1. INTRODUCTION	1
2. INSTRUMENTATION DEVELOPMENT	2
2.1 Secular strain monitor	2
2.2 Special band-pass filter	2
2.3 Drift compensator	2
3. SEISMOGRAPH DEVELOPMENT	3
3.1 Short-period strain and inertial seismograph improvements	3
3.2 Long-period strain seismograph	3
3.2.1 General	3
3.2.2 Environmental tests and monitors	3
3.2.3 Long-period strain seismograph	5
3.2.4 Transducer noise	5
3.2.5 Evaluation	5
3.3 Horizontal strain seismometers	5
4. EVALUATION	5
4.1 Vertical strain seismograph	5
4.2 Evaluation of improved horizontal strain housing	6
5. APPLICATIONS	8
5.1 Recording and processing of data	8
5.2 Strain directional array	10
5.3 Wave identification	10
5.4 Operation and analysis procedures manual	14
APPENDIX - Statement of work to be done	

## ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Phase spread of four horizontal strain-inertial seismograph combinations showing improvements after installation of 3.0 cps galvanometers in all phototube amplifiers and special filters in strain channels	4
2	Power spectra density of recording by the east strain seismograph of 15-20 mph wind noise, before the placement of additional overburden on the horizontal strain housing, 21 January 1966 and after the placement, 2 March 1967	7
3	Seismogram, recorded online, illustrating the ability of the strain directional array to azimuthally discriminate between microseisms exhibiting directional properties. Rejection and enhancement are shown for 5-second microseisms by the southwest and northeast elements, respectively	11
4	Seismogram, recorded online, illustrating the effectiveness of the strain directional array to azimuthally discriminate between microseisms exhibiting directional properties. Rejection and enhancement are shown for 2.0 cps train noise by the southeast and northwest elements, respectively	12
5	Seismogram, recorded online, illustrating enhancement of the horizontal component of the primary and surface phases of a near regional event by the east and northeast elements of the strain directional array. The epicenter is approximately N 60°E from WMSO	13
6	Polar plots of the relative vertical displacement U2, horizontal displacement U1, vertical differential displacement E22, horizontal differential displacement E11, due to incident longitudinal waves plotted as a function of the angle of incidence. The values of differential displacement, E22 and E11, have been multiplied by 50 for improved resolution	15

#### ABSTRACT

Eleven seismograph channels at WMSO were converted to a "3-cycle" system, resulting in a significant improvement in matching of phase response of strain-inertial combinations. A substantial increase in utility of the short-period strain directional array data was achieved by a transition from offline summing to online summing of strain and inertial signals.

A combination of long-period horizontal strain and inertial seismographs with matched frequency responses was put into operation at WMSO to evaluate its directional capabilities. An equivalent inertial magnification of 12K at 25 seconds has been achieved with the long-period strain seismograph. Magnifications of 50K-100K are required to reject long-period microseisms effectively.

A comparison of the steel-cased borehole and the plastic-cased borehole indicates that 6-second microseisms are recorded with approximately 30 percent less amplitude in the steel-cased borehole. Further comparison will be made by interchanging seismometers in the two boreholes.

Relative theoretical values of displacement and differential displacement have been computed for incident longitudinal waves as part of the study of wave discrimination.

## MULTICOMPONENT STRAIN SEISMOGRAPH

### 1. INTRODUCTION

This report discusses technical findings and accomplishments in a program of strain seismology under Contract AF 33(657)-15288 in the period 1 January to 31 March 1967. The work reported herein covers development of a system of 3-component strain and 3-component short-period inertial seismographs having matched amplitude and phase responses in the frequency range 0.01-10 cps.

This report is submitted in compliance with Item 6 of Exhibit A, Statement of Work to be Done, AFTAC Project Authorization No. VELA T/5081. The report is presented in the same sequence as the tasks in the Statement of Work. The Statement of Work is included as an appendix.

At the beginning of this quarter, the following outstanding problems existed:

- a. The need for improved phase matching of short-period horizontal strain-inertial combinations;
- b. Evaluation of the short-period directional array required much off-line data processing;
- c. Unstable system magnifications;
- d. Noise produced by the moving-coil transducer in the long-period horizontal strain seismograph limited system magnification to an equivalent inertial magnification of 6K at 25 seconds;
- e. Existence of an apparent phase discrepancy in the vertical strain seismograph, possibly caused by the magnetostrictive calibrator;
- f. Indications that the steel-cased borehole does not respond to ground motion properly, whereas the plastic-cased hole does.

Briefly, the status of these problems at the end of the quarter are as follows:

- a. The phase match of the short-period horizontal strain combinations has been significantly improved and is now closely matched on all directional array channels as a result of converting to a "3-cycle" system.
- b. A transition to online operation of the directional array has simplified evaluation of the short-period strain directional array.
- c. Sections of quartz tubing found cracked or broken where the calibrators are attached, have been replaced. Stability checks have been resumed.



d. Noise has decreased 6 dB on the long-period moving-coil horizontal strain seismograph over a period of several weeks. To identify the source of remaining noise will possibly require several months of testing.

e. Instrumentation to monitor motion of the magnetostrictive calibrator under field operating conditions is being built in order to resolve the question of a phase discrepancy in the calibrator.

f. Additional analysis indicates apparent loss of signal (6-second microseisms) in the steel-cased borehole. Seismometers in the two boreholes will be interchanged.

## 2. INSTRUMENTATION DEVELOPMENT

### 2.1 SECULAR STRAIN MONITOR

Earlier operation of the secular strain monitor revealed the need for enclosing the recorder, a 16-millimeter Bolex movie camera, in a sealed container to minimize the penetration of moisture into the camera. Moisture causes the film to jam at the film gate. The camera has been installed in a sealed container with a desiccant and has been operating properly since 16 February 1967. Data are presently being recorded and will be evaluated during the next quarter.

### 2.2 SPECIAL BAND-PASS FILTER

A six-channel special band-pass filter was designed and fabricated for use in the strain seismographs. This filter replaces the 0.8 cps galvanometers and differentiators formerly used in the strain channels and provides an improved phase match between strain and inertial seismographs. The filter has a center frequency of 0.8 cps with 3 dB points at 0.4 and 1.5 cps. High and low frequency cutoff rates are 6 dB/octave. Phase responses of the six channels indicate a very close match with theoretical values and approximately  $\pm 1^\circ$  phase spread.

### 2.3 DRIFT COMPENSATOR

In order to evaluate the horizontal strain variable capacitance (VC) transducer, it is necessary to minimize long-term dimensional changes in the quartz tubing. A drift compensator has been designed in which the output signal of the VC transducer controls the power to a heater. This heater, in turn, determines the temperature of an insulated slug which expands or contracts as necessary for compensation.

Preliminary tests indicate that the approach is feasible. More detailed tests are in progress.

### 3. SEISMOGRAPH DEVELOPMENT

#### 3.1 SHORT-PERIOD STRAIN AND INERTIAL SEISMOGRAPH IMPROVEMENTS

Phase response tests of the strain seismograph phototube amplifier with 0.8 cps galvanometers indicated deviations from theoretical values which produced serious phase mismatches between strain-inertial seismograph combinations. These phase errors were discussed in Quarterly Report (QR) No. 6.

An improved system (also discussed in QR No. 6) was designed using identical 3 cps galvanometers in all channels with special band-pass filters in the strain channels to match the inertial seismometers. Initial tests at WMSO indicated a significant improvement in phase match and steps were taken to assemble the necessary equipment to modify the entire system. A six-channel filter was built and galvanometers on hand were reconditioned.

During the week of 20 March 1967, installation and testing of the improved system was completed. Figure 1 shows the phase spread of the four horizontal strain-inertial seismograph combinations before and after the change. These curves indicate that the strain channels lag the inertials by about 15° before the change and about 5° after the change. Minor adjustments to correct galvanometer damping errors in strain channels will further improve the phase match.

Phase and amplitude stability of the improved system will be determined and reported when sufficient data have been collected.

#### 3.2 LONG-PERIOD STRAIN SEISMOGRAPH

##### 3.2.1 General

Long-period strain work, which was discussed in QR No. 6, was started at WMSO during this period. Several steps were necessary before operation of the long-period horizontal strain seismograph could be attempted.

##### 3.2.2 Environmental Tests and Monitors

Pressure tests were performed on the horizontal strain vault complex and all leaks were sealed. A leak test showed the vault time constant to be greater than 5 hours. The microbarograph was installed in the central vault and data from the long-period and short-period channels are being recorded on the long-period Develocorder.

A temperature monitoring system was also installed to assist in the evaluation of the seismograph. Four sensors monitor the temperature of the north strain transducer, the north strain quartz standard, the east strain quartz standard, and the air in the central vault. Diurnal temperature changes in the vault are less than 0.2°C. Changes in temperature of the quartz standard are much smaller.

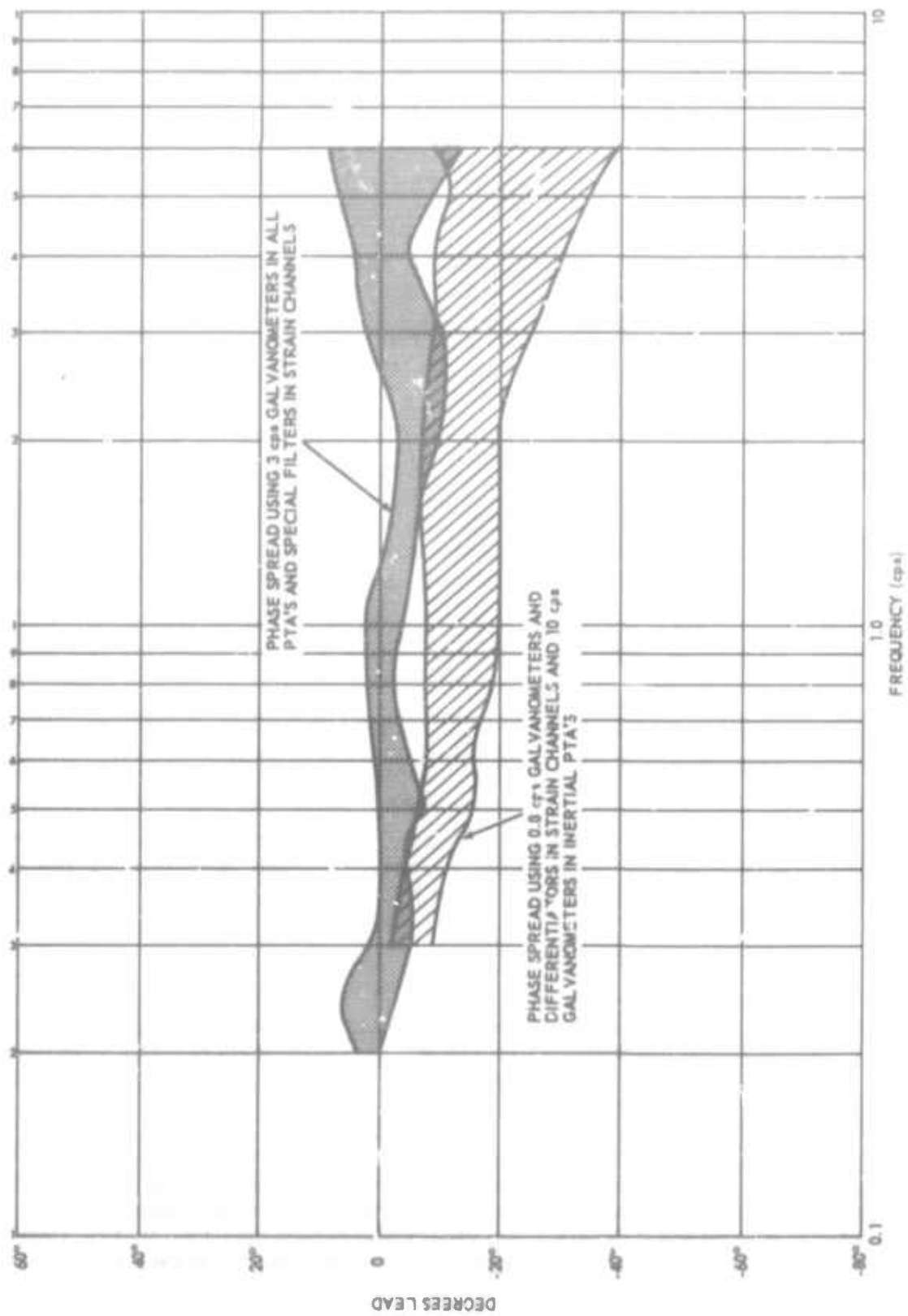


Figure 1. Phase spread of four horizontal strain inertial seismograph combinations showing improvements after installation of 3.0 cps gal vanometers in all phototube amplifiers and special filters in strain channels

G 2491

Finally, a baffle was installed in the vertical entrance shaft of the central vault to minimize temperature variations during entry.

### 3.2.3 Long-Period Strain Seismograph

The north strain instrument was chosen for long-period work and operates into a Model 5240A phototube amplifier (PTA) with a 110-second galvanometer. The PTA is followed by a special band-pass filter to match the response of the long-period inertial seismograph. After initial tests, the circuit was modified to permit recording of both short-period and long-period data from a single strain transducer.

### 3.2.4 Transducer Noise

Initial tests indicated that mechanical noise in the moving-coil transducer exceeded electrical noise by approximately 20 dB in the frequency band of interest. This noise limited strain magnification to an equivalent inertial magnification of 6K at 25 seconds. A styrofoam convection shield was constructed and placed around the transducer. Several minor modifications to the transducer were made, including replacement of the aluminum extension tube with a section of quartz tubing. After a stabilization period of about 3 weeks, the mechanical noise was reduced by approximately 6 dB and has continued at this level. A major modification of the moving-coil transducer will be necessary to further reduce mechanical noise.

### 3.2.5 Evaluation

Data from the WMSO long-period north inertial seismograph are being recorded on the long-period Develocorder with long-period north strain data; long-period strain magnification is 8000K at 25 seconds, which is equivalent to an inertial magnification of 12K. Recording of the inertial channel was delayed due to extensive seismometer maintenance by observatory personnel. Data for final evaluation will be recorded on tape in the near future.

## 3.3 HORIZONTAL STRAIN SEISMOMETERS

Broken sections of the quartz tube standards of the north and northwest strain seismometers were replaced and new calibrators were installed. New calibrator constants were also obtained for all four horizontal strain seismometers with the use of the variable capacitance transducer.

## 4. EVALUATION

### 4.1 VERTICAL STRAIN SEISMOGRAPH

To compare the response to ground motion of the steel-cased and plastic-cased boreholes, amplitude measurements were taken from selected samples of large 4- to 6-second microseisms that appeared to be Rayleigh waves.

The differential displacement recorded by each vertical strain seismograph was compared to a theoretical value computed for Rayleigh waves using the displacement measured by the vertical inertial seismograph. The average ratio of empirical to theoretical values of vertical differential displacement is 0.94 for the steel-cased borehole and 1.4 for the plastic-cased borehole. Although the results for the steel-cased borehole agree more closely with theory (based on a value of 0.25 for Poisson's ratio), a comparison of the two ratios suggests the occurrence of less signal in the steel-cased borehole than in the plastic-cased hole.

The ratio of differential displacement recorded by the summed orthogonal horizontal strain seismographs was compared to that recorded by each vertical strain seismograph. The average of these ratios is 3.6 for the steel-cased borehole and 2.4 for the plastic-cased borehole. Theory predicts a ratio of approximately 3.0. These results bear out tendencies observed in spectra shown in QR No. 6.

#### 4.2 EVALUATION OF IMPROVED HORIZONTAL STRAIN HOUSING

Improvements to the horizontal strain housing were made during the middle of 1966. Included among the improvements was the placement of an additional 1.3 meters of overburden over the horizontal strain seismometers to reduce the susceptibility of the strain seismographs to wind generated noise.

Recordings by the east strain seismograph, before and after the above work was accomplished, were selected to evaluate the reduction in recorded wind noise. The recordings were selected from times when wind velocities were between 15 to 20 miles per hour. The east strain seismograph was selected because it is nearest the surface, due to the terrain variations at the WMSO strain installation, and therefore affected most by wind.

Figure 2 is a plot of the power spectra density of the two wind noise recordings. At frequencies greater than 0.8 cps, the noise recorded on 2 March 1967 is seen to be significantly reduced from that recorded on 21 January 1966. Some differences due to microseismic variations might be expected; however, this cannot account for the differences seen in figure 2. This is borne out by the 2 cps region, a spectral high at WMSO. The spectral peak of the 2 cps microseisms is prominent on the 1967 sample, but fairly well camouflaged by wind noise on the 1966 sample. The level of 2 cps microseisms at WMSO is usually fairly constant as a function of time.

The increase at 3 cps on the 1967 recording is attributed to the presence of microseisms. These 3 cps microseisms were observed on both the strain and inertial seismograph recordings made on 16 mm film.

Although the susceptibility of the horizontal strains to wind noise, specifically the east strain, has not been removed, it has been reduced by the additional overburden above the horizontal strain trenches.

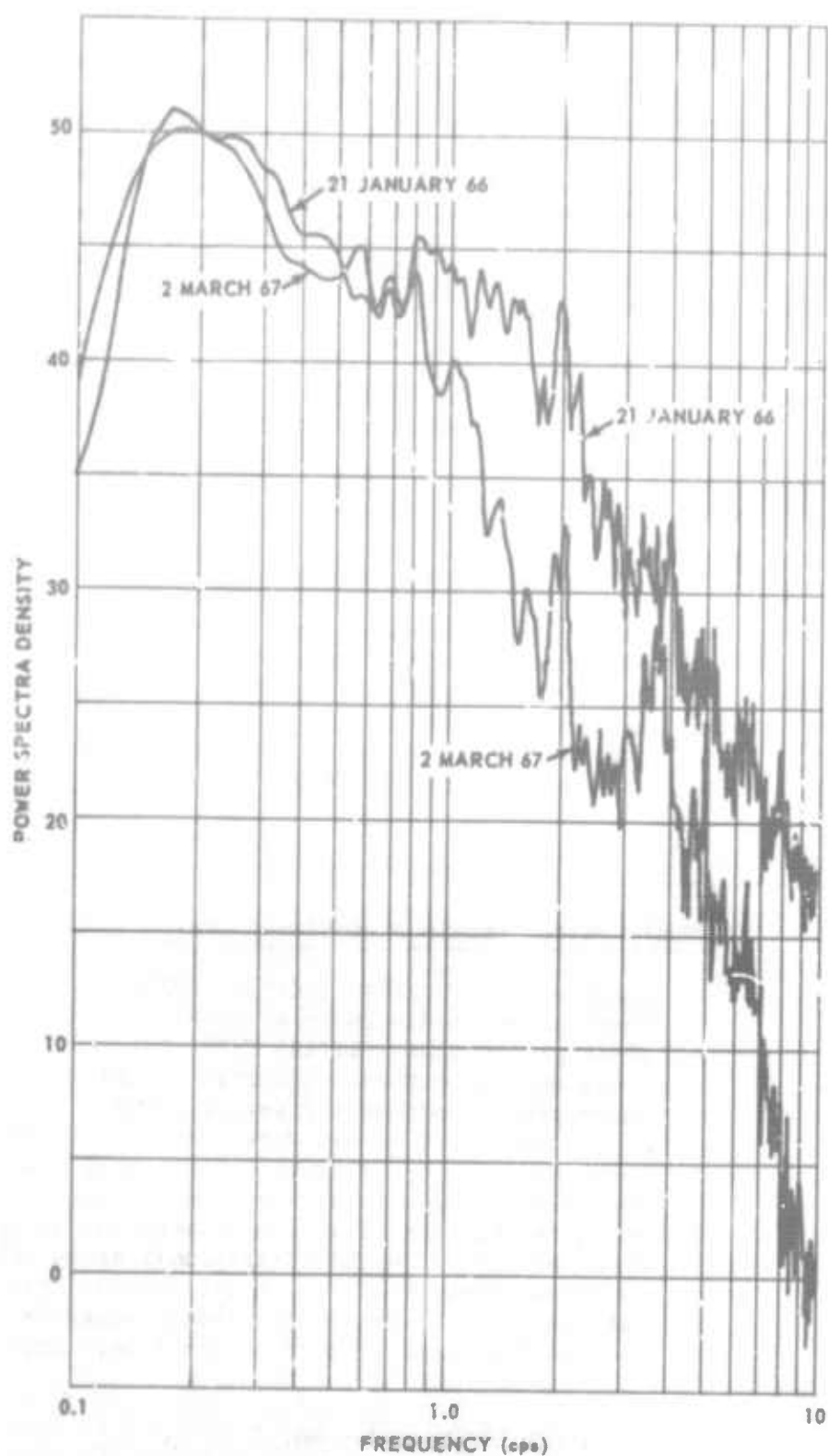


Figure 2. Power spectra density of recording by the east strain seismograph of 15-20 mph wind noise, before the placement of additional overburden on the horizontal strain housing, 21 January 1966 and after the placement, 2 March 1967

G 2492

## 5. APPLICATIONS

### 5.1 RECORDING AND PROCESSING OF DATA

Short-period and long-period strain and inertial seismic data are being recorded at WMSO. The short-period system consists of 6 strain and 5 inertial seismographs. The long-period systems consist of 1 horizontal strain and 1 inertial seismograph. Pressure and temperature variations inside the strain seismometer housing are monitored continuously.

The strain and inertial seismic data are being recorded on three 16 mm film Develocorders and two Ampex magnetic-tape recorders. The following list the recorders and the trace or channel assignments presently in use.

#### WMSO Develocorder No. 5

##### Long-period strain

<u>Trace No.</u>	
1.	Short-period microbarograph (SPMB)
2.	Reference line (Dead Trace)
3.	Long-period north strain (SNL)
4.	Long-period north inertial (NLP)
5.	Long-period microbarograph (LPMB)
6.	Temperature monitor (Temp)

#### WMSO Develocorder No. 6

##### Short-period strain directional array

<u>Trace No.</u>	
1.	Short-period vertical inertial (SPZ)
2.	Short-period north inertial (SPN)
3.	Short-period east inertial (SPE)
4.	Short-period northeast inertial (SPNE)
5.	Short-period northwest inertial (SPNW)
6.	North element of strain directional array (N)
7.	Northeast element of strain directional array (NE)
8.	East element of strain directional array (E)
9.	Southeast element of strain directional array (SE)
10.	South element of strain directional array (S)
11.	Southwest element of strain directional array (SW)
12.	West element of strain directional array (W)
13.	Northwest element of strain directional array (NW)

#### WMSO Develocorder No. 7

##### Short-period strain primary

<u>Trace No.</u>	
1.	Short-period north inertial (SPN)
2.	Short-period north strain (SNS)



Trace No.

3. Summation of SNS and SES ( $\Sigma$ SNS, SES)
4. Short-period east strain (SES)
5. Short-period east inertial (SPE)
6. Short-period north inertial (SPN)
7. Short-period vertical inertial (SPZ)
8. Short-period vertical strain in steel-cased borehole ( $SZS_1$ )
9. Short-period vertical strain in plastic-cased borehole ( $SZS_2$ )
10. Short-period northeast inertial (SPNE)
11. Short-period northeast strain (SNES)
12. Summation of SNES and SNWS ( $\Sigma$ SNES, SNWS)
13. Short-period northwest strain (SNWS)
14. Short-period northwest inertial (SPNW)
15. Anemometer (Wind)

WMSO magnetic-tape recorder No. 2

Channel No.

1. BCD station time
5. Long-period north strain (SNL)
6. Long-period north inertial (NLP)
7. Compensation
14. Voice comment

WMSO magnetic-tape recorder No. 3

Channel No.

1. BCD station time
2. Short-period north inertial (SPN)
3. Short-period east inertial (SPE)
4. Short-period north strain (SNS)
5. Short-period east strain (SES)
6. Short-period northeast inertial (SPNE)
7. Compensation
8. Short-period northwest inertial (SPNW)
9. Short-period northeast strain (SNES)
10. Short-period northwest strain (SNWS)
11. Short-period vertical strain in plastic-cased borehole ( $SZS_2$ )
12. Short-period vertical inertial (SPZ)
13. Short-period vertical strain in steel-cased borehole ( $SZS_1$ )
14. Voice comment

The 16 mm film records are being analyzed at Geotech to evaluate the use of strain data for signal enhancement and wave identification. These records are also being used to select seismic noise and events for more detailed studies by magnetic-tape data processing. Both analog and digital data processing are being performed at the Geotech Data Processing Center in Garland.



## 5.2 STRAIN DIRECTIONAL ARRAY

The ability of given elements of the strain directional array to enhance signal by microseismic rejection and signal addition have been demonstrated by offline processing, TR 66-5, TR 65-45, and TR 67-2. Online recording of the directional array has been initiated to establish the feasibility of online recording and minimize offline processing.

The effectiveness of the directional array to azimuthally discriminate between low velocity microseisms which appear to have single source origins is illustrated in figures 3 and 4. Figure 5 shows the enhancement of the horizontal components of the primary and surface phases of a near regional earthquake by certain elements of the directional array.

The azimuthal ambiguity relating to the 5-second microseisms, figure 3, is removed by the directional array. Azimuth indications obtained from the inertial recordings are indefinite whereas the directional array shows the 5-second microseisms to be arriving from the ENE.

Figure 4 illustrates how signal, 2 cps train noise, can be either reduced or enhanced by elements of the directional array. Train noise is generated several degrees east from south of WMSO and hence the north and south elements will provide maximum reduction and enhancement, respectively; however, at the time the recordings were taken, the north strain was being operated as a long-period system only. Therefore, in figure 4, the southeast element exhibits maximum enhancement and the northwest element maximum reduction.

The recording of a near regional by the directional array is shown in figure 5. Again the north strain is missing from the north and south elements of the array. Enhancement of the horizontal component of displacement by the east and north-east elements is readily apparent. The epicenter is approximately N 60°E from WMSO. The occurrence of signal on all elements of the array is to be expected from this azimuth.

Recording and analysis of online data will be continued to further evaluate the potential of the directional array, both in signal enhancement and as a tool in the study of microseisms.

## 5.3 WAVE IDENTIFICATION

Displacement and differential displacement due to incident SV waves were discussed in Quarterly Report No. 6. Employing the same parameters used in the SV wave computations, relative displacement and differential displacement due to longitudinal waves have been computed. The horizontal displacement, differential displacement, and vertical displacement were computed for zero depth (surface). The vertical differential displacement was computed between points 18 and 36 meters below the surface. Poisson's ratio was assigned a value of 0.3, the normal stress along the surface was assumed to be zero, and a frequency of 1 cps was used for all computations.

$$\text{Magnification} = \left( \frac{\text{Strain magnification}}{26} \right) + \text{inertial magnification} \quad \text{where}$$

$$\frac{\text{Strain magnification}}{26} = \frac{\text{equivalent inertial magnification (equated for seismic wave of apparent surface velocities of 3.0 km/sec)}}{26}$$

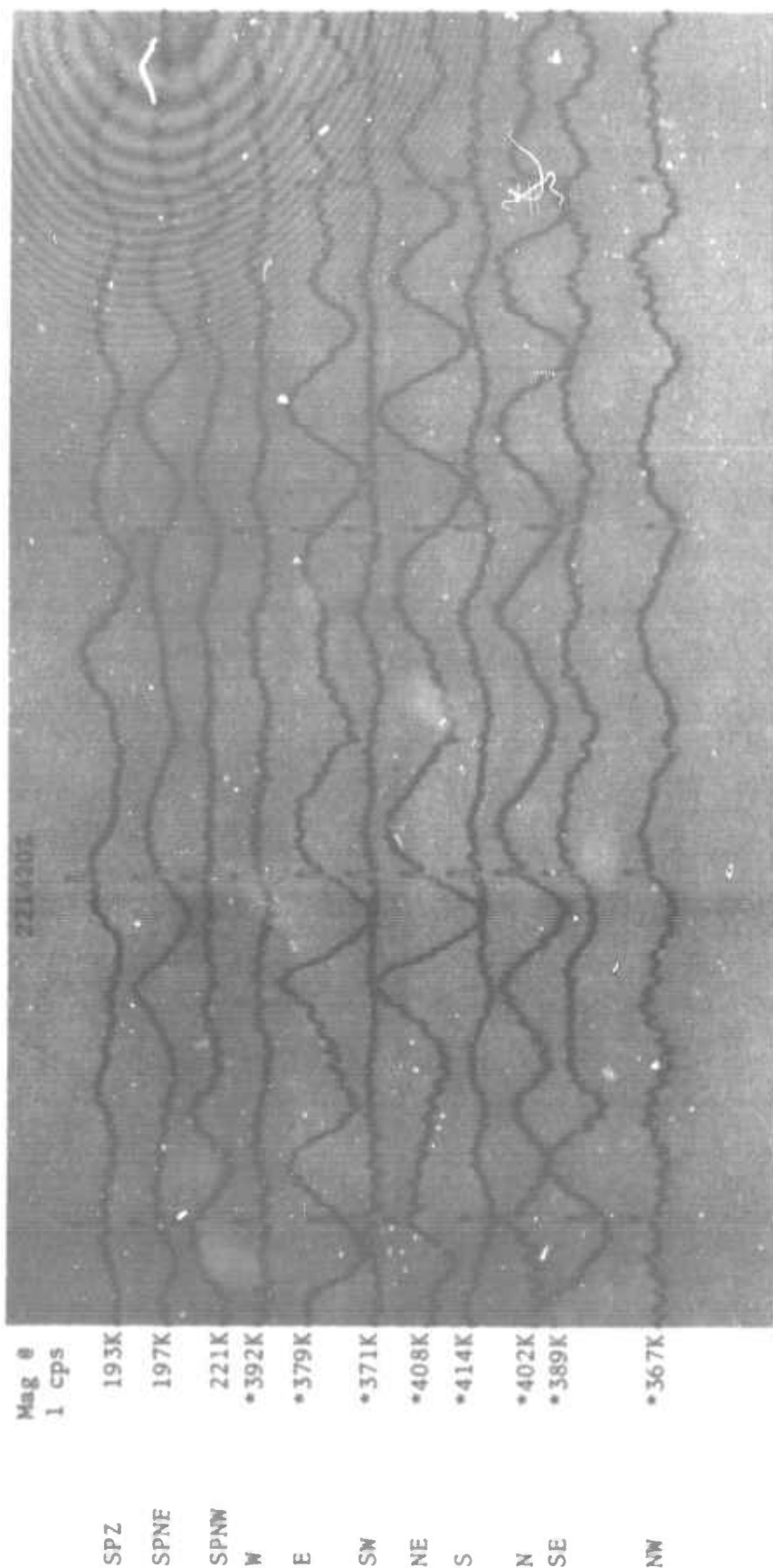


Figure 3. Seismogram, recorded online, illustrating the ability of the strain directional array to azimuthally discriminate between microseisms exhibiting directional properties. Rejection and enhancement are shown for 5-second microseisms by the southwest and northeast elements, respectively

WMSO  
Record No. 076  
17 Mar 67

$$\text{Magnification} = \left( \frac{\text{Strain magnification}}{26} \right) + \text{inertial magnification} \quad \text{where}$$

$$\frac{\text{Strain magnification}}{26} = \text{equivalent inertial magnification (equated for seismic wave of apparent surface velocities of 3.0 km/sec)}$$

SPZ	Mag @
SPNW	1 cps
SPNE	193K
W	232K
E	188K
SW	*409K
NE	*409K
SPN	*367K
SPN	*421K
SE	-
NW	-
	*416K
	*408K

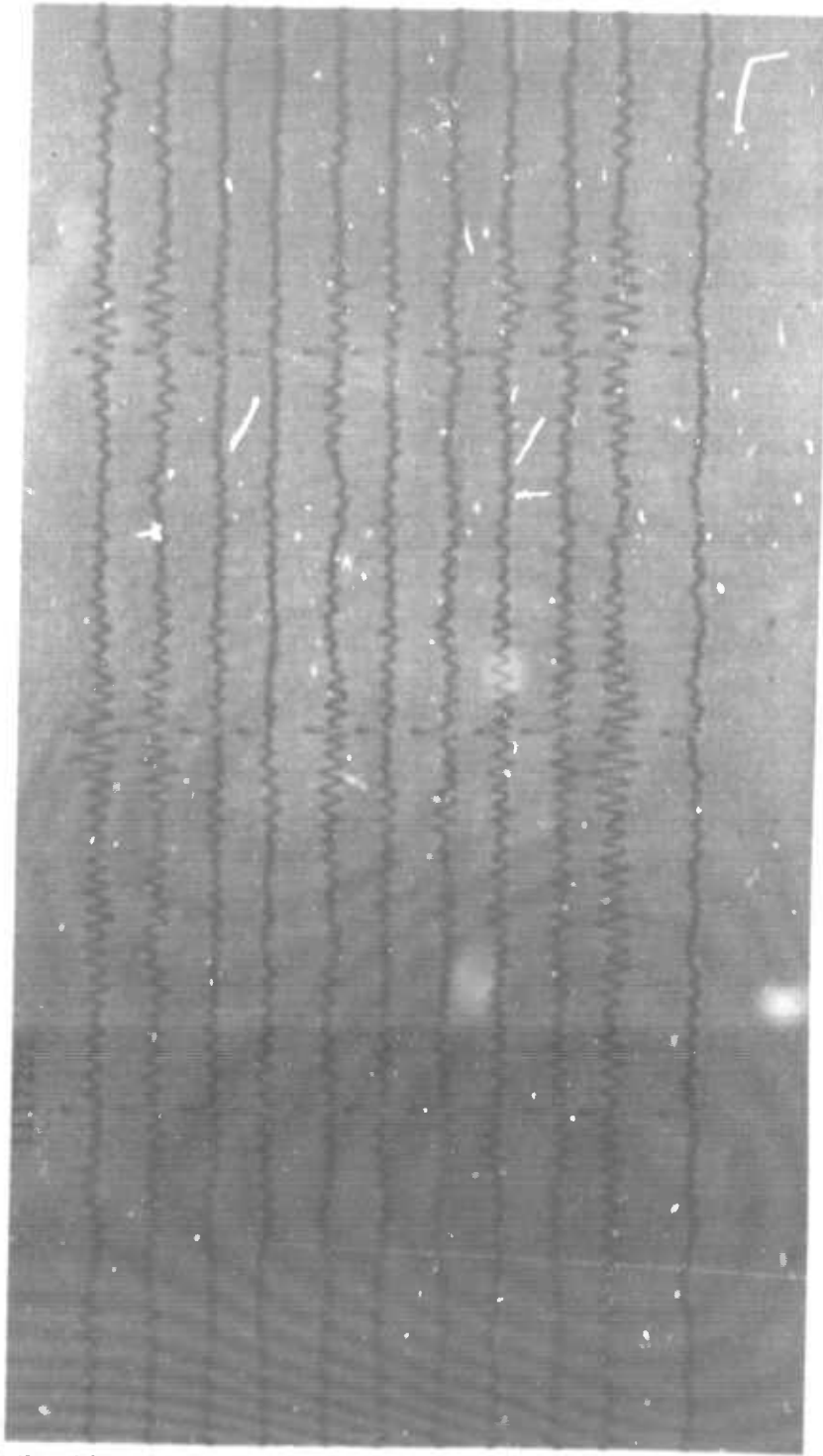


Figure 4. Seismogram, recorded online, illustrating the effectiveness of the strain directional array to azimuthally discriminate between microseisms exhibiting directional properties. Rejective and enhancement are shown for 2.0 cps train noise by the southeast and northwest elements, respectively

MMSO  
Record No. 069  
8 Mar 67

$$\text{Magnification} = \left( \frac{\text{Strain magnification}}{26} \right) + \text{inertial magnification} \quad \text{where}$$

$$\frac{\text{Strain magnification}}{26} = \text{equivalent inertial magnification (equated for seismic wave of apparent surface velocities of 3.0 km/sec)}$$

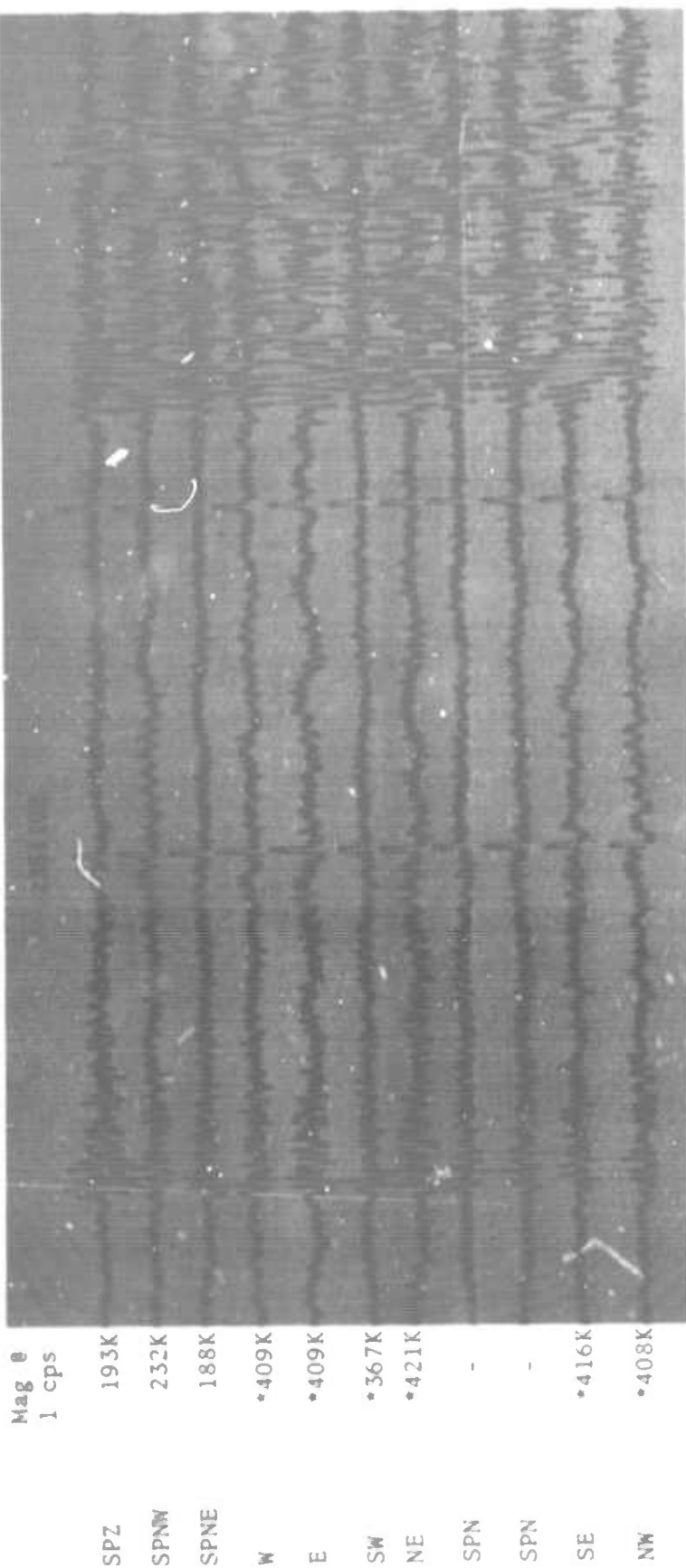


Figure 5. Seismogram, recorded online, illustrating enhancement of the horizontal component of the primary and surface phases of a near regional event by the east and northeast elements of the strain directional array.  
The epicenter is approximately N 60°E from WMSO

WMSO  
Record No. 068  
9 Mar 67

Polar plots of the displacement and differential displacement as a function of angle of incidence are shown in figure 6. The values of differential displacement have been multiplied by 50 for improved resolution. The plots show the magnitudes of the horizontal (E11) and vertical (E22) differential displacement to be similar for most angles of incidence, as might be expected from examination of the relationship of vertical to horizontal strain where the vertical stress is zero. Because there will be no vertical strain when a longitudinal disturbance is vertically incident, it is interesting to note the occurrence of vertical differential displacement; however, it will only be 0.053 percent of the vertical displacement.

Although the amplitudes of the vertical and horizontal differential displacement are similar for most angles of incidence, their phase relationship is not constant due to a relative change in phase of the vertical differential displacement as a function of angle of incidence. With respect to the phase of both vertical and horizontal displacement, which are the same, the phase of vertical differential displacement ranges from in phase at  $0^\circ$  incidence to about  $-90^\circ$  as the incidence approaches  $90^\circ$ . The phase of the horizontal differential displacement is a  $+90^\circ$  with respect to displacement for all angles of incidence.

#### 5.4 OPERATION AND ANALYSIS PROCEDURES MANUAL

Theoretical and empirical amplitude and phase response data for strain and inertial seismographs are being collected for the operations section of the Procedures Manual. System operating parameters and seismometer and galvanometer characteristics are also being tabulated.

Theoretical vertical and horizontal strain for varying epicentral distances has been computed and the results will be included in the analysis section of the manual.

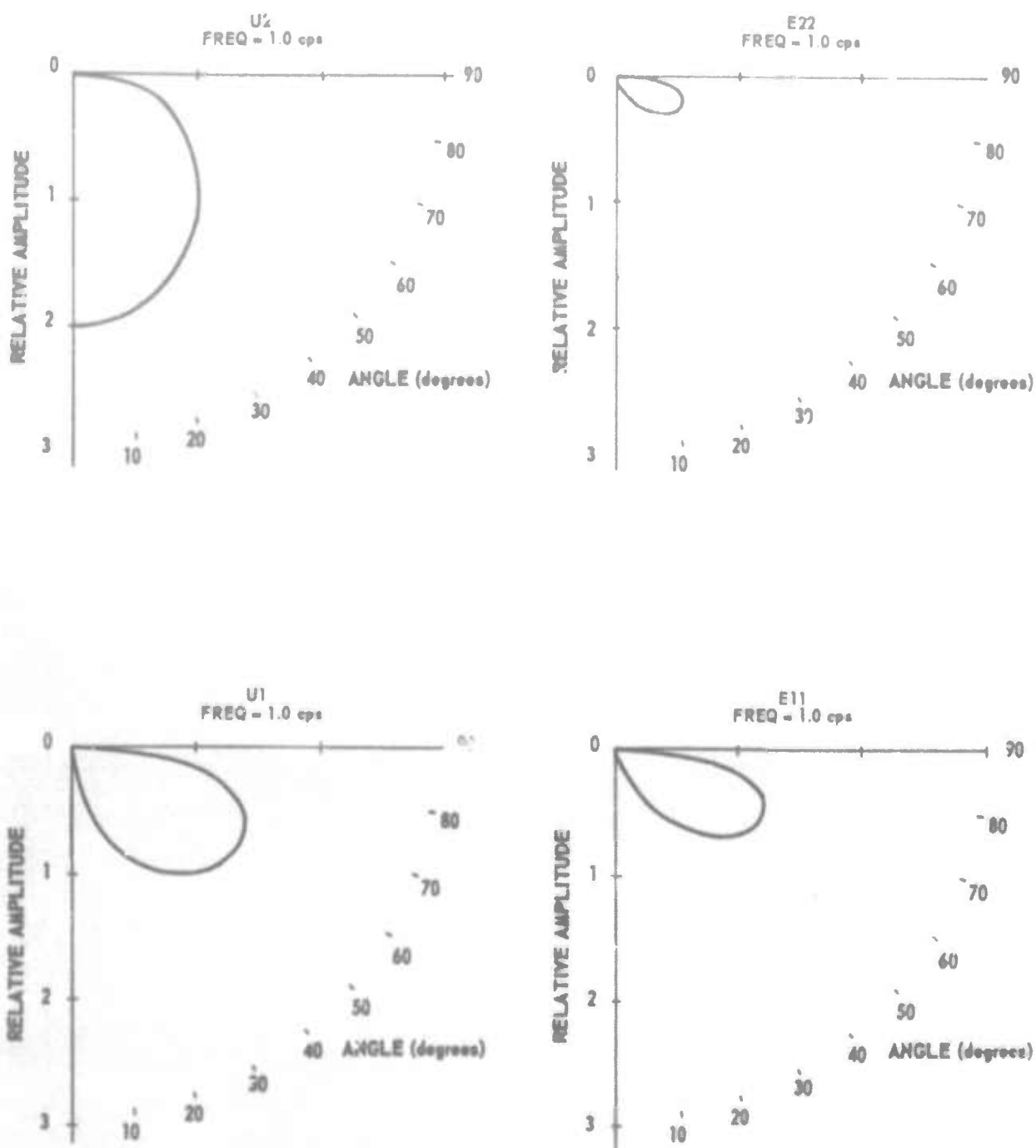


Figure 6. Polar plots of the relative vertical displacement  $U_2$ , horizontal displacement  $U_1$ , vertical differential displacement  $E_{22}$ , horizontal differential displacement  $E_{11}$  due to incident longitudinal waves plotted as a function of the angle of incidence. The values of differential displacement,  $E_{22}$  and  $E_{11}$ , have been multiplied by 50 for improved resolution.

G 2493

APPENDIX TO TECHNICAL REPORT NO. 67-15

STATEMENT OF WORK TO BE DONE  
AFTAC PROJECT AUTHORIZATION NO. VELA T/5081



## EXHIBIT "A"

### STATEMENT OF WORK TO BE DONE

AFTAC Project Authorization No. VELA T/5081

#### 1. Instrumentation Development

- a. Complete the development of the variable-capacitance transducer to extend the strain seismograph response to longer periods.
- b. Complete the modification and testing of the seismometer transducers, amplifiers, filters, and associated circuitry to insure a consistent phase relationship between pendulum and strain seismographs.
- c. Design and install secular strain monitors to improve the horizontal strain seismograph operation.
- d. Improve the stability of the seismograph circuitry by installing a separate phototube amplifier shelter.

#### 2. Seismograph Development

##### a. Vertical Strain Seismograph

(1) Complete this design of the vertical strain seismograph by improving the anchor design, reshaping the instrument sections, and improving the mechanical reliability relative to installation, position locking, and removal.

(2) Improve the operation of the vertical strain seismograph by incorporating the developments listed in paragraphs 1a, 1b, and 2a(1).

##### b. Horizontal Strain Seismographs

(1) Improve the design of the horizontal strain seismographs by the addition of secular strain controls and seismograph housing modifications.

(2) Improve the operation of the horizontal strain seismographs by incorporating the developments listed in paragraphs 1a, 1b, 1c, 1d, and 2b(1).

REPRODUCTION

AF 33(657)-15288



## EXHIBIT "A" (Cont'd)

### 3. Evaluation

a. Vertical Strain Seismograph. Test and evaluate the operation of the improved vertical strain seismograph in a new uncased borehole to be located adjacent to the present cased borehole. The uncased borehole is to be oil-filled and may contain the following features:

(1) Steel casing sections may be used for instrument anchor locations if the sections are decoupled from each other so that longitudinal casing rigidity is less than that of the surrounding rock formation.

(2) A continuous plastic casing may be used to maintain wall smoothness and hole integrity provided that the plastic is more compliant than the surrounding rock formation.

(3) Combinations of (1) and (2) may be used. In all instances where instrument anchors must lock against a borehole liner, the liner must be rigidly bonded to the borehole wall.

To facilitate the positioning of the instrument in the borehole, a permanent anchor may be used in the cased and uncased holes. This fixed depth operation might help to avoid the anchor malfunctioning which has been experienced.

b. Horizontal Strain Seismographs. Test and evaluate the operation of the improved horizontal strain seismographs in their improved housing.

### 4. Applications

a. Record seismic data at Wichita Mountains Seismological Observatory on magnetic tape and 16 mm film; process magnetic tape data at the Geotechnical Corporation's central data processing facility and elsewhere as required; and determine spectra, phase, and coherency among the vertical strain, horizontal strain, and several pendulum seismometer control signals.

b. Experimentally corroborate the vertical strain seismograph performance relative to the 2 crossed-horizontal strain seismographs to verify that true earth strains are faithfully recorded by the vertical strain instrument.

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## EXHIBIT "A" (Cont'd)

c. Develop a thorough understanding and evaluation of the phase and amplitude performance of the strain seismographs and related pendulum systems.

d. Determine the usefulness of strain seismographs when used singularly and in combination with inertial instruments for wave identification, signal enhancement, detection of long-period signals, and rejection of noise arriving from selected azimuths. Determine the usefulness of strain seismographs in distinguishing between earthquakes and explosions. Schedule the program so as to provide preliminary results on the P-wave enhancement portion of the program not later than 30 Sept 65.

\*5. Drawings. Provide drawings and specifications on items specified in paragraphs 2a(1), 2a(2), 2b(1), 2b(2), and the uncased borehole as outlined in paragraph 3 according to Data Items E-23-11.0, E-2-11.0, E-4-11.0, E-5-11.0, E-7-11.0, and T-13-28.0 contained in AFSCM 310-1. These drawings shall conform to the instructions contained in Attachment 2. Wherever Data Items conflict with Attachment 2, the latter will take precedence. Reproduction shall be accomplished in accordance with Data Item E-4-11.0, paragraphs 1b, 1f, 7, 9, 10, 11, and 12c(3), microfilm on aperture cards and nonreproducible paper copies. Index card keypunch format may vary from specifications as approved by AFTAC through the project officer. Aperture cards should be furnished in 2 copies, 1 positive and 1 negative.

6. Reports. Provide monthly, quarterly, final, milestone, and special progress reports in accordance with Data Item S-17-12.0, first sentence of paragraph 1. Wherever the Data Item conflicts with Attachment 1, the latter will take precedence. All reports under this project will be forwarded to HQ USAF (AFTAC/VELA Seismological Center), Wash., D. C. 20333.

\*For the purposes of this contract, the provisions of paragraph 5 of this Exhibit "A" are hereby waived. In lieu thereof, the following provisions shall apply:

"5. Drawings. Drawings shall be furnished in accordance with the provisions of line item 7 of the DD Form 1423 and attachments thereto."

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## 13. ABSTRACT

Eleven seismograph channels at WMSO were converted to a "3-cycle" system, resulting in a significant improvement in matching of phase response of strain-inertial combinations. A substantial increase in utility of the short-period strain directional array data was achieved by a transition from offline summing to online summing of strain and inertial signals.

A combination of long-period horizontal strain and inertial seismographs with matched frequency responses was put into operation at WMSO to evaluate its directional capabilities. An equivalent inertial magnification of 12K at 25 seconds has been achieved with the long-period strain seismograph. Magnifications of 50K-100K are required to reject long-period microseisms effectively.

A comparison of the steel-cased borehole and the plastic-cased borehole indicates that 6-second microseisms are recorded with approximately 30 percent less amplitude in the steel-cased borehole. Further comparison will be made by interchanging seismometers in the two boreholes.

Relative theoretical values of displacement and differential displacement have been computed for incident longitudinal waves as part of the study of wave discrimination.

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